

## Assessment of Land Use Land Cover Changes and Climate Variability as Evidence of Desertification in Yusufari Lga, Yobe State, Nigeria

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doi: <https://doi.org/10.37745/bjesr.2013/vol14n32746>

Published April 17, 2026

**Citation:** Ejeh L.U. and Agbo E.B. (2026) Assessment of Land Use Land Cover Changes and Climate Variability as Evidence of Desertification in Yusufari Lga, Yobe State, Nigeria, *British Journal of Earth Sciences Research*, 14(3),27-46

*Land degradation and desertification pose severe ecological and socio-economic challenges in arid and semi-arid regions, particularly in Northern Nigeria. This study assesses the spatial and temporal trends of desertification in Yusufari Local Government Area (LGA), Yobe State, Nigeria, from 1991 to 2021, using Geographic Information Systems (GIS) and Remote Sensing (RS) techniques. Landsat satellite imagery (TM, ETM+, and OLI-TIRS) for 1991, 2001, 2011, and 2021 was classified to map Land Use Land Cover (LULC) changes, with a focus on desert area dynamics. Climatic data (rainfall and temperature) from 1991 to 2020 were analyzed to examine variability and its relationship with desertification. Results indicate a significant decline in desert-covered areas, from 1,128.03 km<sup>2</sup> (29.27%) in 1991 to 686.08 km<sup>2</sup> (17.80%) in 2021, reflecting an average annual reduction of 14.73 km<sup>2</sup> and a total contraction of 441.95 km<sup>2</sup> (39.18%). Conversely, vegetation cover increased from 1,082.66 km<sup>2</sup> (28.09%) to 1,620.51 km<sup>2</sup> (42.05%) over the same period, representing a 49.68% expansion. Bare land remained dominant but fluctuated, peaking at 1,786.35 km<sup>2</sup> (46.35%) in 2011 before declining to 1,519.44 km<sup>2</sup> (39.43%) in 2021, while built-up areas expanded marginally from 11.94 km<sup>2</sup> (0.31%) to 27.60 km<sup>2</sup> (0.72%). Accuracy assessments of classified images yielded overall accuracies ranging from 82% to 93%, with Kappa coefficients between 0.76 and 0.91, confirming reliable LULC mapping. Climatic analysis revealed an increasing trend in annual rainfall, with a minimum of 325.3 mm (1992) and maximum of 629.9 mm (2012), and a slight rise in mean temperature over the study period, peaking at 29.56°C in 2010. Statistical correlation using Pearson's coefficient showed a strong negative relationship between desertification and rainfall ( $r = -0.78$ ), though not statistically significant ( $p = 0.22 > 0.05$ ). Temperature exhibited a weak negative correlation with desertification ( $r = -0.25$ ), also not statistically significant ( $p = 0.75 > 0.05$ ). The findings suggest that desertification in Yusufari has receded over the past three decades, likely due to a combination of climatic variability and human interventions such as land restoration and afforestation efforts. The study underscores the value of integrated GIS and RS in monitoring environmental degradation and supports the need for sustained land management policies to combat desertification. Recommendations include further investigation into the drivers of vegetation recovery, enhanced use of high-resolution imagery for detailed monitoring, and the development of predictive models to aid in sustainable land use planning.*

**Keywords:** desertification, land use land cover change, climate variability, GIS, remote sensing, Sahel, Yusufari, Nigeria

## INTRODUCTION

Land degradation represents the most profound and escalating environmental challenge of the Anthropogenic, constituting a direct threat to global ecological stability, economic security, and human well-being. Contemporary research (IPBES, 2019, 2022; IPCC, 2022) defines this not as a simple alteration of land cover but as a systemic, often irreversible, reduction in the biological productivity and economic utility of terrestrial ecosystems. This decline manifests as the collapse of critical ecosystem services: the loss of fertile soil, the failure of water regulation, the breakdown of nutrient cycles, and the erosion of biodiversity. The economic ramifications are staggering, with recent analyses suggesting annual global losses exceeding 10% of Gross Domestic Product, a figure that dwarfs most economic recessions (ELD Initiative, 2022).

The crisis is inextricably linked to the other planetary emergencies climate change and biodiversity loss creating a dangerous feedback loop: degraded lands lose their carbon sequestration capacity, exacerbating climate change, which in turn increases climatic extremes that further drive degradation (IPCC, 2019). The global political recognition of this emergency is embodied in two pivotal frameworks: the United Nations Sustainable Development Goals (SDGs), particularly Goal 15 (Life on Land), which targets combating desertification and restoring degraded land by 2030, and the UN Decade on Ecosystem Restoration (2021-2030) (United Nations, 2015, 2021). These initiatives underscore that land restoration is no longer a niche environmental concern but a cornerstone of global sustainable development.

The drivers of this crisis are universally recognized as a complex amalgam of proximate and underlying factors. Direct causes include unsustainable agricultural expansion, deforestation, overgrazing, and poor irrigation practices leading to salinization. These are propelled by indirect, systemic drivers: population dynamics, market failures, weak governance, insecure land tenure, and poverty, which collectively force communities into short-term exploitation of long-term resources (ELD Initiative & UNEP, 2021; Borrelli et al., 2020). Climate change acts as the ultimate threat multiplier, intensifying degradation through increased temperatures, altered precipitation patterns, and a higher frequency of droughts and floods, thereby reducing the resilience of ecosystems worldwide (IPCC, 2022).

### **Desertification: A Global Perspective**

A severe and geographically concentrated manifestation of global land degradation is desertification specifically, the degradation of land in arid, semi-arid, and dry sub-humid regions. It is critical to dispel the common misconception that desertification is the natural expansion of existing deserts. Rather, it is the consequence of human-induced land degradation in vulnerable dryland ecosystems, leading to desert-like conditions where none existed before (UNCCD, 2019). The process is a stark embodiment of interconnected ecological failures: extreme soil erosion by wind and water, catastrophic loss of perennial vegetation cover and biodiversity, depletion of soil organic carbon (the very foundation of soil fertility and water-holding capacity), and the encroachment of invasive species (Yukie et al., 2020; Práválie et al., 2021).

The visual evidence of desertification is a landscape in retreat: a patchwork of degradation hotspots that gradually merge, leading to the relentless advance of sand dunes over farms and settlements, the siltation of rivers and reservoirs, and the transformation of once-productive rangelands into barren stretches. The global scope of this issue remains alarmingly vast. Recent, refined geospatial analyses confirm that drylands cover approximately 46.2% of the global land area and are home to nearly 3 billion people a population characterized by high levels of poverty and vulnerability to climatic shocks (Práválie et al., 2021; IPCC, 2019). These regions are not marginal; they are central

to global food systems and livelihoods, making their degradation a direct threat to international stability and human security (Ejeh et al. 2025).

### **The African Desertification Crisis**

The African continent continues to bear a disproportionate and intensifying burden of the desertification crisis. Recent continental assessments (AUDA-NEPAD, 2023; Gichenje et al., 2019) indicate that over 65% of Africa's arable land is degraded, with sub-Saharan Africa standing as a primary global hotspot. This is not a passive environmental process but an active socio-ecological crisis. The region's high dependence on rain-fed agriculture which supports over 60% of the population and extensive pastoralism make its economies and food systems exquisitely sensitive to land health (Olsson et al., 2019).

The drivers are deeply entrenched: agricultural expansion driven by population growth often occurs through the clearing of forests and savannas on fragile soils; overgrazing exceeds the carrying capacity of rangelands; and an overwhelming reliance on biomass for energy perpetuates deforestation. In many nations, biomass still supplies 50-80% of domestic energy, creating a relentless demand for fuelwood and charcoal (FAO, 2022). The interaction with climate change is particularly devastating for Africa. The continent is warming at a rate faster than the global average, and increased aridity in regions like the Sahel exacerbates water stress and ecosystem vulnerability (IPCC, 2022). The consequences of this degradation-climate nexus are catastrophic and multidimensional. They include chronic food and water insecurity, the loss of livelihood assets for millions, entrenched poverty, and forced migration. Land degradation is increasingly recognized as a key, yet often overlooked, driver of conflict and displacement on the continent, as communities compete over dwindling productive resources (Abel et al., 2019; IPBES, 2022).

### **Nigeria's Desertification Frontline**

Nigeria stands as a critical and acutely vulnerable epicenter of this desertification crisis within West Africa. National assessments (FMENV, 2021; Nwilo et al., 2021) estimate that between 50% and 60% of the country's land is degraded, with the northern states experiencing some of the most rapid rates of ecological decline on the continent. Eleven northern "frontline states" exist in a state of ecological precarity, facing a synergistic onslaught of climatic and anthropogenic pressures.

The most immediate driver is the unsustainable harvest of trees for energy. Fuelwood and charcoal remain the dominant energy source for over 70% of households in northern Nigeria, creating an economy of deforestation that is both a cause and consequence of poverty (Akinsanola & Ogunjobi, 2020). Concurrently, agricultural practices are often extractive, with shortened fallow periods and limited use of soil amendments, leading to nutrient depletion on already fragile soils (Rowland & Ikpe 2025).

The Northeast geopolitical zone comprising Adamawa, Bauchi, Borno, Gombe, Taraba, and Yobe represents the catastrophic front line of this national environmental crisis. This region is beset by mutually reinforcing stressors, making it arguably one of the most vulnerable areas in Africa. It is the most climatically vulnerable zone in Nigeria, with the lowest and most erratic rainfall, the highest temperatures, and the most frequent droughts (Eze, 2023). The regional hydrological crisis is epitomized by the tragedy of the Lake Chad Basin, which has shrunk by over 90% since the 1960s due to reduced inflows and unsustainable irrigation withdrawals, destroying fisheries and displacing entire communities (UNEP, 2021).

## **Yobe State: Epicenter at State Level**

Yobe State, situated in the heart of the Nigerian Sahel within the Northeast zone, stands as the unequivocal epicenter of the desertification crisis at the state level. Its geographical and climatic profile defines its inherent vulnerability: it lies within the Sudano-Sahelian agro-ecological zone, characterized by fragile, sandy soils, low annual rainfall (ranging from 350mm in the north to 600mm in the south), and a long, harsh dry season lasting up to eight months (Yobe State Ministry of Environment, 2022).

Recent state-level geospatial assessments (Sawa & Garba, 2021; Akpoti et al., 2022) confirm that over 70% of the state's land area exhibits moderate to severe indicators of desertification. The physical manifestations are visible and accelerating: aggressively mobile sand dunes engulf farmlands and settlements; native vegetation, including key drought-resistant species like *Acacia senegal*, is in sharp decline; and groundwater tables are falling precipitously. The human dimension encapsulates a devastating poverty-environmental degradation trap. A largely agrarian population, with limited access to alternative livelihoods or clean energy, is compelled by immediate survival needs to cut trees for fuel and charcoal while cultivating marginal lands without restorative inputs, systematically eroding the land's resilience (Ariko et al. 2024).

## **Yusufari LGA: Study Area Rationale**

Yusufari Local Government Area, the study site located in the extreme northern fringe of Yobe State, serves as a critical case study of localized ecological collapse. Yusufari epitomizes the hyper-arid frontier of the Sahel. Recent climatic trend analyses (2019-2024) utilizing aridity indices show increasing mean annual temperatures coupled with decreasing and highly erratic rainfall, effectively pushing the region towards hyper-aridity (Eze, 2023). The area experiences frequent and severe droughts, with the rainy season now compressed and unreliable. Empirical evidence of degradation is overwhelming: analysis of satellite-derived indices reveals a consistent negative trend in vegetation vigor over the past five years, while high-resolution imagery shows the dramatic expansion of bare ground and active dune fields at the expense of formerly stable grasslands and cultivated areas.

## **Research Gap and Study Objectives**

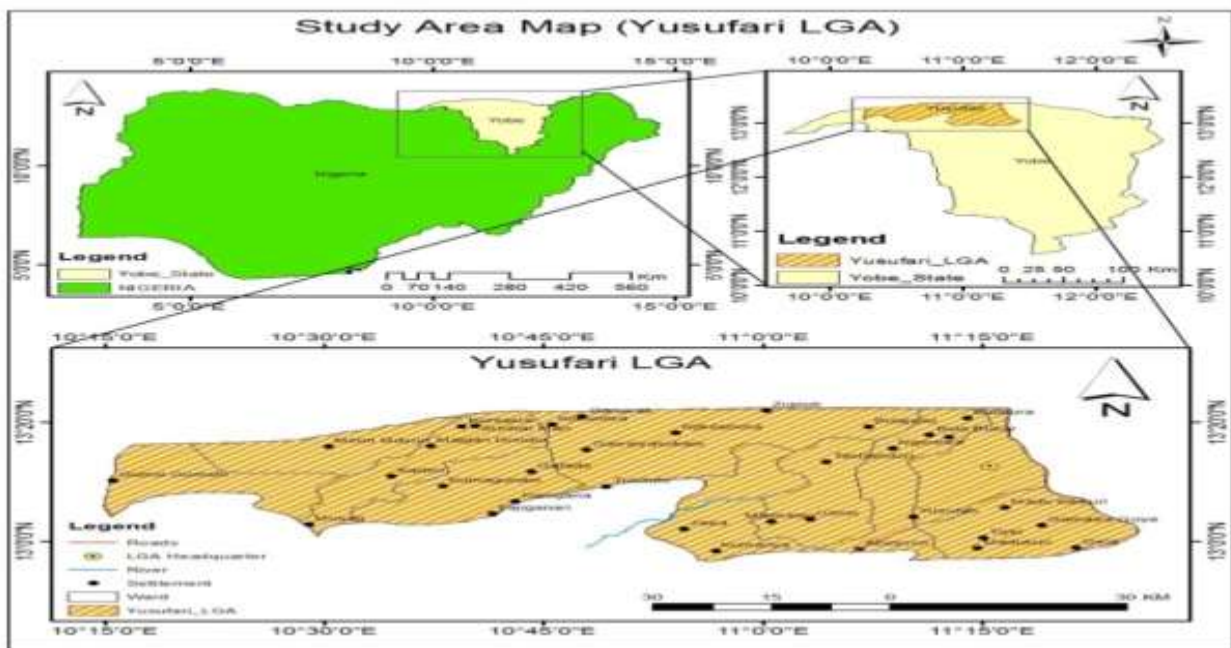
While the macro-level narrative of desertification in Northern Nigeria is well-established, the accelerating pace of environmental change under contemporary climatic extremes demands hyper-local, temporally recent, and spatially precise assessment. Generalizations at the state or regional level inevitably mask the specific rates, spatial patterns, and dominant drivers operative at the community level. Policymakers and intervention agencies are often hampered by a lack of granular, up-to-date data, leading to generic solutions that fail to address local realities. Consequently, a significant gap exists in current (2019-2024) high-resolution, geospatially explicit data on the progression and specific drivers of desertification in acutely vulnerable areas like Yusufari.

This study is meticulously designed to fill this critical gap through multi-temporal geospatial analysis using recent high-resolution satellite imagery (spanning 2019 to 2024). This research will accurately quantify the spatial extent, rate of change, and landscape evolution of land degradation in Yusufari LGA. It employs advanced remote sensing techniques and geographic information systems to classify land cover changes, map degradation hotspots, and correlate these changes with both biophysical and anthropogenic variables. The output will be an evidence-based land degradation status map and a comprehensive trend analysis report for Yusufari LGA a vital tool for actionable intelligence. The findings will provide the Yobe State Government, the National Great Green Wall Agency, humanitarian organizations, and local community leaders with the

precise information needed to move beyond broad gestures. This will enable the design, targeting, and implementation of resilient, sustainable, and context-specific land restoration and livelihood strategies, whether identifying priority areas for assisted natural regeneration, planning targeted afforestation, designing soil and water conservation structures, or promoting alternative energy sources. In essence, this research aims to turn the tide of data scarcity into informed action, offering a blueprint for combating desertification at the very scale where the battle is being lost and must be won.

## Study Area

This research was conducted within Yusufari Local Government Area (LGA) as shown in figure 1, situated in the northeastern region of Yobe State, Nigeria, a critical frontline zone in the African Sahel. Geographically, the area is bounded by latitudes  $12^{\circ}40'00''\text{N}$  and  $13^{\circ}40'00''\text{N}$ , and longitudes  $10^{\circ}10'00''\text{E}$  and  $11^{\circ}30'00''\text{E}$ , encompassing a total land area of approximately 3,928  $\text{km}^2$ . The LGA shares its western border with Machina and Nguru, its eastern border with Yunusari, its southern border with Karasuwa and Bursari LGAs, and its northern border with the Niger Republic. Its location within the arid to semi-arid Sahelian belt renders it highly vulnerable to desertification and land degradation processes emanating from the Sahara Desert.



**Figure 1: Map of Yusufari LGA**

**Source: Agbo, (2022)**

The climate of Yusufari is tropical, characterized by two distinct seasons. The dry season, spanning from November to April, is dominated by the dry, continental North East Trade Wind originating from the Sahara, associated with high temperatures, low humidity (averaging  $\sim 30\%$  in peak dry months), and the pervasive Harmattan dust haze. The wet season occurs from May to October, influenced by moist maritime air from the Atlantic Ocean, with peak rainfall typically in August. Historical data (1991-2020) indicates a mean annual rainfall of 517.95 mm, though distribution is

highly variable. Temperature regimes show high mean monthly values, with the hottest months (April-June) experiencing maximum temperatures that can exceed 40°C.

The topography is predominantly a flat to gently undulating plain, part of the extensive Borno Plain, interspersed with relic fixed dunes and low sandhills. The drainage system is seasonal, dissecting dune fields. Vegetation is classified as Sudano-Sahelian, comprising scattered xerophytic shrubs, discontinuous seasonal grasses, and riparian woodlands, all significantly altered by anthropogenic pressure. Soils are primarily tropical ferruginous types with low water retention capacity, highly susceptible to wind erosion. The combined effects of poor soil structure, climatic stress, and human activity establish Yusufari as a classic case study for examining desertification dynamics.

## **MATERIALS AND METHODS**

### **Research Design**

This study employed a quantitative, geospatial research design integrating time-series remote sensing analysis with climatological data assessment within a Geographic Information Systems (GIS) environment. The systematic workflow was structured into four sequential phases: reconnaissance and desktop study, data acquisition, data processing and analysis, and data presentation.

### **Data Acquisition**

#### **Satellite Imagery**

The primary spatial data consisted of multi-temporal Landsat satellite imagery acquired at decade intervals:

- Landsat 5 TM (10 December 1991)
- Landsat 7 ETM+ (19 May 2001 and 31 May 2011)
- Landsat 8 OLI-TIRS (18 May 2021)

All images were sourced from USGS GLOVIS/LandViewer (Path/Row: 187/51) and selected from the dry season to maintain phenological consistency.

#### **Climatic Data**

Historical climate data for Yusufari (rainfall and temperature, 1991-2020) were obtained from the Climatic Research Unit Time-Series dataset (CRU TS Version 4.05).

#### **Ground Truth Data**

Supplementary data included ground truth coordinates and photographs collected during field reconnaissance in December 2021 using a Garmin eTrex 10 GPS, along with high-resolution historical imagery from Google Earth Pro for validation.

#### **Image Pre-processing**

All satellite images underwent pre-processing in QGIS 3.22.3 and ArcGIS 10.3.1. This involved geometric correction to UTM Zone 32N (WGS 84), radiometric calibration, and correction of scan-

line errors for the 2011 image. Image enhancement included creating standard false-color composites and pan-sharpening the 2021 image. The study area was subsequently extracted from each scene.

### **Land Use/Land Cover Classification**

Land Use/Land Cover (LULC) classification was performed using an unsupervised approach. The Iterative Self-Organizing Data Analysis (ISODATA) algorithm in ArcGIS was used to identify natural spectral clusters, which were later merged and labeled into four final LULC classes based on spectral signatures and ground truth knowledge:

- Vegetation (encompassing forests, shrubs, grasslands, and farmlands)
- Bare Land (exposed soil, fallow fields, and sparsely vegetated areas)
- Desert Area (active and semi-stabilized sand dunes and sandy plains)
- Built-up Area (settlements and infrastructure)

### **Accuracy Assessment**

Thematic accuracy for each LULC map was assessed using stratified random sampling. Between 54 and 62 reference points per map were compared against high-resolution Google Earth imagery and field data. Error matrices were constructed to calculate Overall Accuracy, Producer's Accuracy, User's Accuracy, and the Kappa statistic.

### **Change Detection**

Change detection was executed using the Post-Classification Comparison (PCC) method. The independently classified maps from different dates were compared pixel-by-pixel using the "Intersection" tool in ArcGIS. This generated change matrices quantifying the area transferred between LULC classes for the intervals 1991-2001, 2001-2011, 2011-2021, and the entire period 1991-2021. Net areal change and annual rates of change (km<sup>2</sup>/yr) were calculated for each class. Thematic maps visualizing the dominant LULC transitions were also produced.

### **Climatic Data Analysis**

Annual rainfall and temperature data were analyzed using Microsoft Excel and SPSS Statistics 20. Time-series graphs with linear trend lines were plotted to identify long-term trends. To test the relationship between desertification and climate, Pearson's correlation analysis was performed. The spatial extent of the "Desert Area" class for the years 1991, 2001, 2011, and 2021 was correlated with the corresponding annual rainfall and mean annual temperature for those specific years.

### **Software and Hardware**

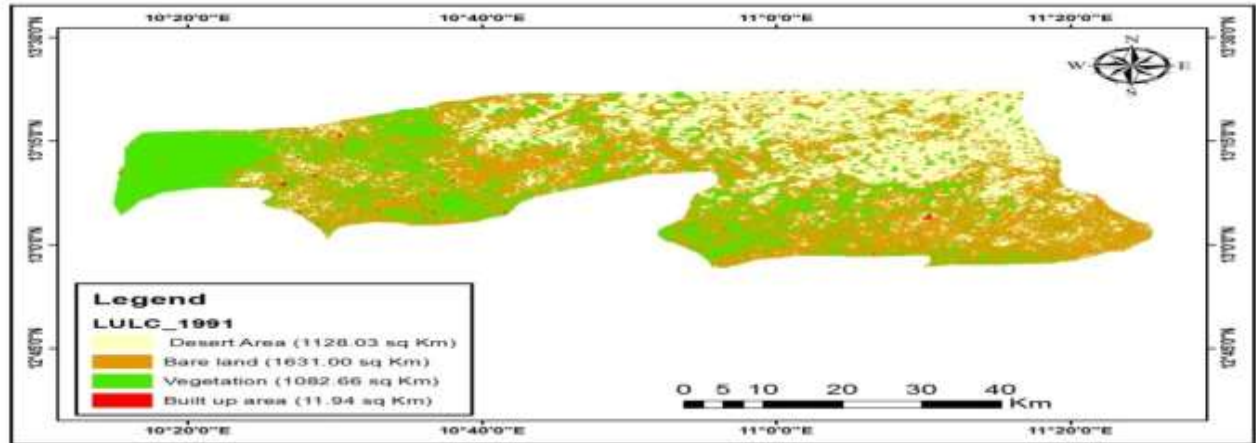
Geospatial analysis was conducted using ArcGIS 10.3.1 and QGIS 3.22.3. Google Earth Pro served as a validation tool. Climatic and statistical analyses were performed in Microsoft Excel and IBM SPSS Statistics 20. All processing was executed on an HP EliteBook 8470p laptop with an Intel Core i7 processor and 8GB RAM.

## RESULTS AND DISCUSSION

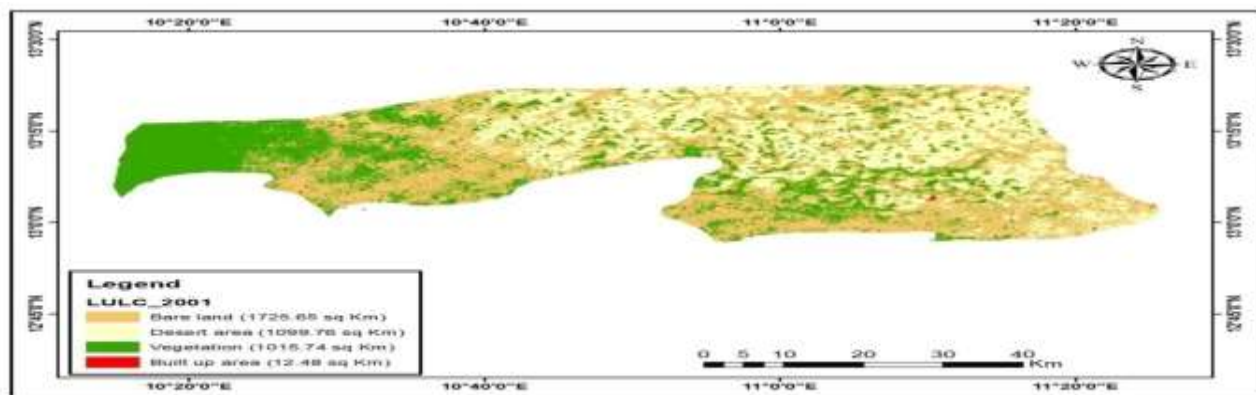
The systematic analysis of multi-temporal satellite imagery and climatic data for Yusufari Local Government Area over a thirty-year period (1991–2021) reveals significant transformations in land cover, challenging the prevailing narrative of inexorable desertification in the Nigerian Sahel. This section presents the empirical findings on land use and land cover (LULC) changes, the spatiotemporal dynamics of desertification, climatic variability, and the statistical interplay between these factors, followed by a comprehensive discussion of their implications.

### Land Use and Land Cover Classification and Validation

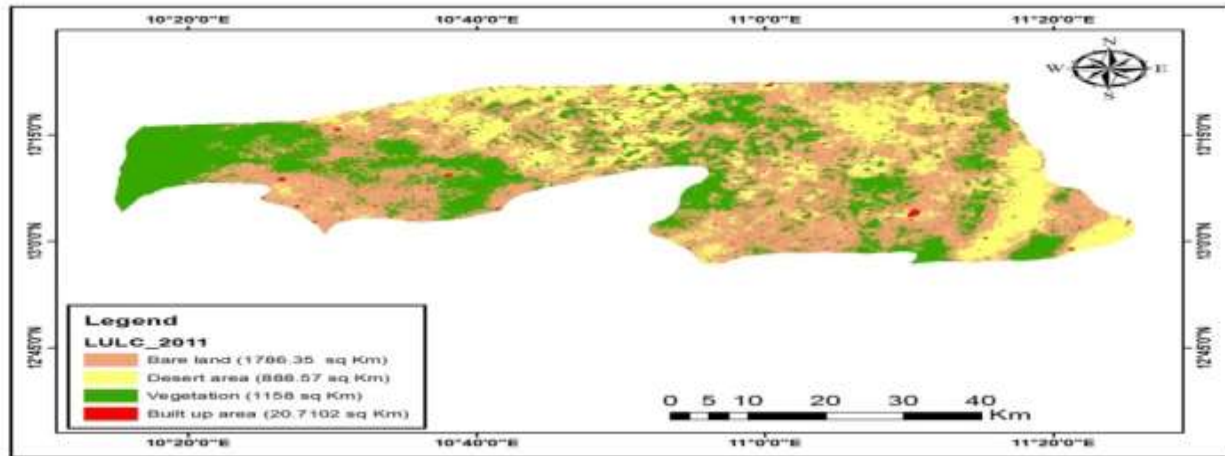
The application of the ISODATA unsupervised classification algorithm to Landsat imagery for the epochs 1991, 2001, 2011, and 2021 yielded consistent and interpretable LULC maps (Figures 2–5).



**Figure 2: LULC Map of Yusufari (1991)**  
Source: Agbo, (2022)

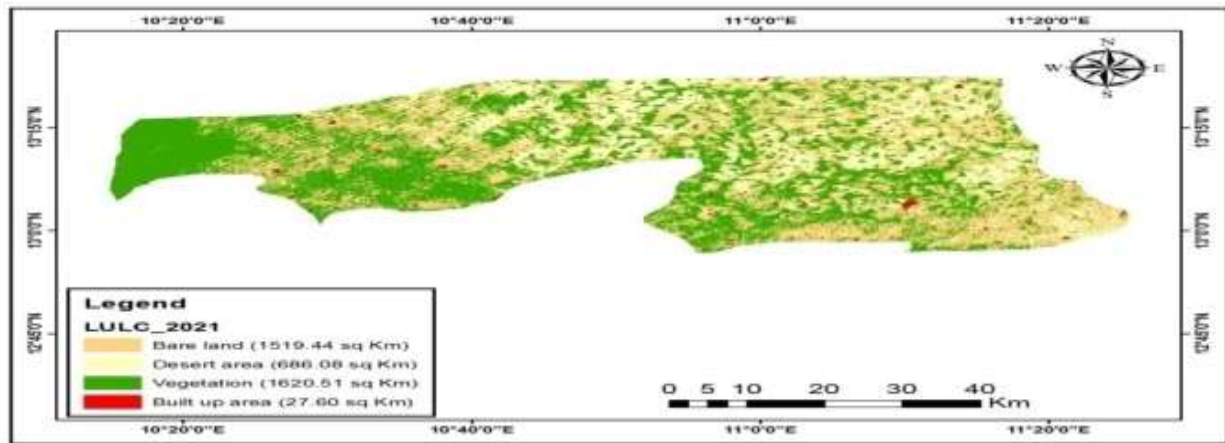


**Figure 3: LULC Map of Yusufari (2001)**  
Source: Agbo, (2022)



**Figure 4: LULC Map of Yusufari (2011)**

Source: Agbo, (2022)



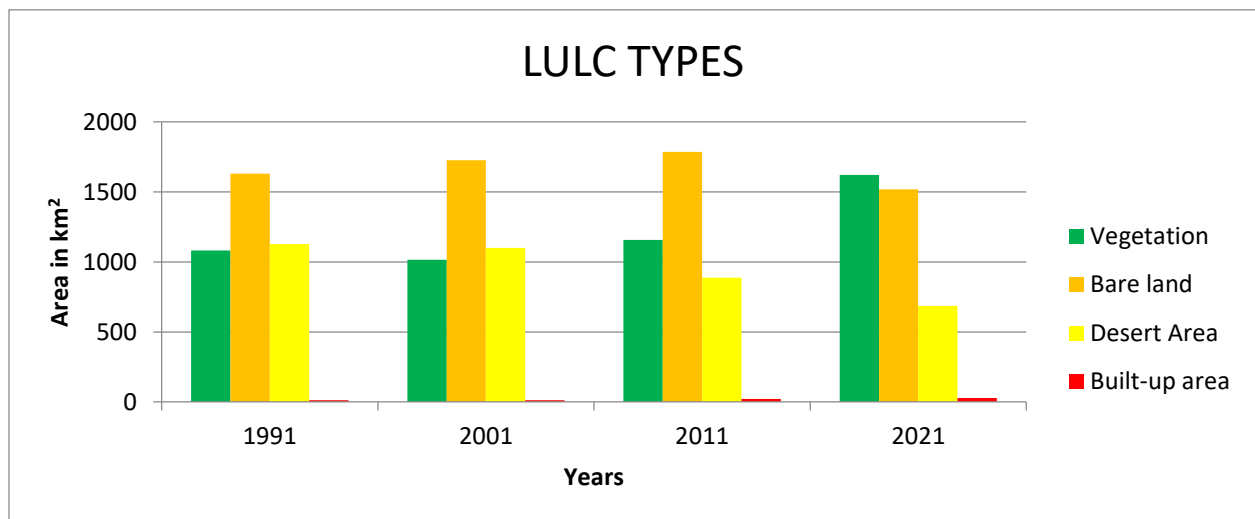
**Figure 5: LULC Map of Yusufari (2021)**

Source: Agbo, (2022)

Four distinct and meaningful classes were delineated across all periods: Vegetation, Bare Land, Desert Area, and Built-up Area. The quantitative breakdown of the aerial extent and proportional coverage of each class is consolidated in Table 1.

**Table 1: Area Covered and Proportion of LULC Class for Each Year**

Class	1991 Area (km <sup>2</sup> )	%	2001 Area (km <sup>2</sup> )	%	2011 Area (km <sup>2</sup> )	%	2021 Area (km <sup>2</sup> )	%
Vegetation	1,082.66	28.09	1,015.74	26.36	1,158.00	30.05	1,620.51	42.05
Bare Land	1,631.00	42.32	1,725.65	44.78	1,786.35	46.35	1,519.44	39.43
Desert Area	1,128.03	29.27	1,099.76	28.54	888.57	23.06	686.08	17.80
Built-up	11.94	0.31	12.48	0.32	20.71	0.54	27.60	0.72
Total	3,853.63	100	3,853.63	100	3,853.63	100	3,853.63	100

**Figure 6: Trends in LULC for the Years 1991, 2001, 2011, and 2021**

Source: Agbo, (2022)

The thematic accuracy of these classifications was rigorously assessed to ensure reliability for change detection. Error matrices were constructed for each epoch using stratified random sample points validated against high-resolution Google Earth imagery and field reconnaissance data. The derived accuracy metrics, presented in a consolidated confusion matrix (Table 2), confirm a high degree of map reliability.

**Table 2: Confusion Matrix of the LULC Classification for Each Year in the Study Area**

LULC Type	1991						
	Vegetation	Bare land	Desert area	Built-up area	Total (user)	User accuracy (%)	
Vegetation	11	2	1	0	14	76%	
Bare land	0	12	1	0	13	92	
Desert area	0	3	12	0	15	80	
Built-up area	0	1	0	11	12	92	
Tota (producer)	11	18	14	11	54		
Producer accuracy (%)	100%	67%	86%	100%			
<b>OVERALL ACCURACY = 85%</b>		<b>Keppa coefficient = 91%</b>					
	2001						
	Vegetation	Bare land	Desert area	Built-up area	Total (user)	User accuracy (%)	
Vegetation	12	2	0	0	14	86	
Bare land	0	13	0	0	13	100	
Desert area	0	0	14	0	14	100	
Built-up area	1	1	0	12	14	86	
Tota (producer)	13	16	14	12	55		
Producer accuracy (%)	92	81	100	100			
<b>OVERALL ACCURACY = 93%</b>		<b>Keppa coefficient = 80%</b>					
	2011						
	Vegetation	Bare land	Desert area	Built-up area	Total (user)	User accuracy (%)	
Vegetation	13	2	0	1	16	81%	
Bare land	2	13	0	0	15	87%	
Desert area	1	2	12	1	16	75%	
Built-up area	1	1	0	13	15	87%	
Tota (producer)	17	18	12	15	62		
Producer accuracy (%)	76%	72%	100	87%			
<b>OVERALL ACCURACY = 82%</b>		<b>Keppa coefficient = 76%</b>					
LULC Type	2021						

	Vegetation	Bare land	Desert area	Built-up area	Total (user)	User accuracy (%)
Vegetation	17	1	0	1	19	89%
Bare land	1	16	0	0	17	88%

Desert area	0	1	15	0	16	94%
Built-up area	1	0	0	9	10	90%
Tota (producer)	19	18	15	10	62	
Producer accuracy (%)	89%	88%	94%	90%		
OVERALL ACCURACY = 85%	Keppa coefficient = 91%					

**Source: Agbo, (2022)**

Overall accuracy ranged from 82.26% (2011) to 92.73% (2001), while the Kappa coefficient varied between 0.76 (2011) and 0.91 (1991 and 2021). User's and Producer's accuracies for individual classes were consistently above 66.67%, with many exceeding 85%. These values meet and often exceed accepted thresholds for land cover change studies, affirming that the classification outputs are robust and suitable for detailed spatiotemporal analysis.

The most salient trend observable in Table 1 is the pronounced shift in landscape composition over three decades. Bare Land remained the dominant class throughout, peaking at 1,786.35 km<sup>2</sup> (46.35%) in 2011, indicative of a landscape under significant ecological pressure. However, the most dynamic and counter-intuitive finding is the substantial and progressive decline of Desert Area, contracting from 1,128.03 km<sup>2</sup> (29.27%) in 1991 to 686.08 km<sup>2</sup> (17.80%) in 2021. This decline is powerfully complemented by the remarkable expansion of Vegetation cover, which surged from 1,082.66 km<sup>2</sup> (28.09%) to 1,620.51 km<sup>2</sup> (42.05%) over the same period, with the most dramatic increase occurring between 2011 and 2021. This inverse relationship suggests a potential reversal of desertification processes within the study area.

### Spatiotemporal Dynamics and Rates of Desertification Change

To isolate and quantify the desertification trend, the spatial extents of the Desert Area class were extracted for each study year. The calculation of decadal and overall rates of change provides a precise measure of this transformation (Table 3).

**Table 3: Rate of Change in Desert Areas for the Study Years**

Year	Desert Area (km <sup>2</sup> )	Period	Rate of Change (km <sup>2</sup> /yr)
1991	1,128.03	1991-2001	-2.83
2001	1,099.76	2001-2011	-21.12
2011	888.57	2011-2021	-20.25
2021	686.08	1991-2021	-14.73

**Sources: Agbo, E.B. (2022)**

The desert area decreased at an average annual rate of -14.73 km<sup>2</sup>/yr over the entire 30-year period, amounting to a total net loss of 441.95 km<sup>2</sup> of desert cover a 39.18% reduction. The decadal analysis reveals that the most rapid phase of desert retreat occurred between 2001 and 2011, with a striking rate of -21.12 km<sup>2</sup>/yr. This was followed by a continued but slightly slower decline of -

20.25 km<sup>2</sup>/yr from 2011 to 2021. The initial decade (1991–2001) showed a much more modest rate of change (-2.83 km<sup>2</sup>/yr), indicating that the reversal process may have accelerated after 2001.

### Land Cover Transition Pathways and Consumption Analysis

Beyond net changes, post-classification comparison (PCC) unveils the complex underlying transitions between land cover types. The cross-tabulation matrices for each study interval detail the "consumption" of one class by another, offering critical insights into the mechanisms of landscape change. The annual rate of change for all LULC classes is summarized in Table 4.

**Table 4: Percentage Gain or Loss and Annual Rate of LULC Change**

LULC Class	1991 (km <sup>2</sup> )	2001 (km <sup>2</sup> )	Area Change (km <sup>2</sup> ) (1991-2001)	% Change	RATE OF CHANGE /YEAR (km <sup>2</sup> /yr)
Vegetation	1082.66	1015.74	-66.92	-6.18	-6.69
Bare land	1631.00	1725.65	94.65	5.80	9.46
Desert Area	1128.03	1099.76	-28.27	-2.51	-2.83
Built-up area	11.94	12.48	0.54	4.53	0.05
<b>Total</b>	<b>3853.63</b>	<b>3853.63</b>			
	<b>2001 (km<sup>2</sup>)</b>	<b>2011 (km<sup>2</sup>)</b>	<b>(2001-2011)</b>		
Vegetation	1015.74	1158.00	142.26	14.01	14.23
Bare land	1725.65	1786.35	60.70	3.52	6.07
Desert Area	1099.76	888.57	-211.19	-19.20	-21.12
Built-up area	12.48	20.71	8.23	65.94	0.82
<b>Total</b>	<b>3853.63</b>	<b>3853.63</b>			
	<b>2011 (km<sup>2</sup>)</b>	<b>2021 (km<sup>2</sup>)</b>	<b>(2011-2021)</b>		
Vegetation	1158	1620.51	462.51	39.94	46.25
Bare land	1786.35	1519.44	-266.91	-14.94	-26.69
Desert Area	888.57	686.08	-202.49	-22.79	-20.25
Built-up area	20.71	27.60	6.89	33.26	0.69
<b>Total</b>	<b>3853.63</b>	<b>3853.63</b>			
	<b>1991 (km<sup>2</sup>)</b>	<b>2021 (km<sup>2</sup>)</b>	<b>(1991-2021)</b>		
Vegetation	1082.66	1620.51	537.85	49.68	17.93
Bare land	1631.00	1519.44	-111.56	-6.84	-3.72
Desert Area	1128.03	686.08	-441.95	-39.18	-14.73
Built-up area	11.94	27.60	15.66	131.16	0.52
<b>Total</b>	<b>3853.63</b>	<b>3853.63</b>			

Source: Agbo, (2022)

### Climatic Variability Trends (1991–2020)

The analysis of the 30-year climatic record for Yusufari provides the environmental context for the observed land cover changes (Tables 5 and 6).

**Table 5: Rainfall Records (1991-2020)**

Years	Annual Rainfall (mm)	Years	Annual Rainfall (mm)
1991	409.1	2006	399.8
1992	325.3	2007	453.2
1993	325.5	2008	429.9
1994	578.8	2009	350.1
1995	358.6	2010	517.5
1996	367.2	2011	425.0
1997	350.2	2012	629.9
1998	389.7	2013	440.5
1999	509.1	2014	395.3
2000	357.0	2015	359.5
2001	460.8	2016	475.0
2002	324.5	2017	491.6
2003	537.1	2018	537.1
2004	337.8	2019	463.7
2005	513.9	2020	542.9

**Source: Climatic Research Unit Time-Series dataset (CRU TS Version 4.05), 2022**

**Table 6: Temperature Records (1991-2020)**

Years	Mean Temp. (°C)	Years	Mean Temp. (°C)
1991	28.52	2006	28.91
1992	27.73	2007	28.85
1993	28.38	2008	28.36
1994	28.02	2009	29.43
1995	28.45	2010	29.56
1996	28.61	2011	29.00
1997	28.73	2012	28.78
1998	28.88	2013	29.34
1999	28.77	2014	29.10
2000	28.10	2015	28.62
2001	28.33	2016	29.19
2002	28.62	2017	28.64
2003	28.72	2018	28.64
2004	28.83	2019	28.48
2005	28.87	2020	28.47

**Source: Climatic Research Unit Time-Series dataset (CRU TS Version 4.05), 2022**

Rainfall exhibited high inter-annual variability, with a minimum of 325.3 mm (1992) and a maximum of 629.9 mm (2012). A linear trend analysis indicates a gradual increase in mean annual rainfall. Concurrently, mean annual temperature showed an upward trend, consistent with global warming patterns, peaking at 29.56°C in 2010 before a slight moderation.

**Climatic Context Discussion:** The observed marginal increase in rainfall aligns with a partial recovery from the catastrophic Sahelian droughts. This climatic amelioration likely provided a more favourable hydrologic regime. However, the concurrent rise in temperature imposes continued evaporative stress. The climatic data alone cannot adequately explain the magnitude of the dramatic land cover reversal.

### Statistical Relationship between Desertification and Climatic Elements

To objectively evaluate the direct climatic influence, a Pearson correlation analysis was performed between the spatial extent of the Desert Area class and the key climatic variables for the four corresponding snapshot years (Tables 7 and 8).

**Table 7: Desert, Rainfall and Temperature Data for the Study Period**

Year	Desertification (km <sup>2</sup> )	Rainfall (mm)	Temperature (°C)
1991	1,128.03	409.1	28.52
2001	1,099.76	460.8	28.33
2011	888.57	425.0	29.00
2021	686.08	542.9	28.47

Source: Agbo, (2022)

**Table 8: Pearson Correlation Coefficient between Desertification, Rainfall and Temperature**

		Desertification	Rainfall	Temperature
Desertification	Pearson Corr.	1	-0.78	-0.25
	Sig. (2-tailed)		0.22	0.75
	N	4	4	4
Rainfall	Pearson Corr.	-0.78	1	-0.40
	Sig. (2-tailed)	0.22		0.60
	N	4	4	4
Temperature	Pearson Corr.	-0.25	-0.40	1
	Sig. (2-tailed)	0.75	0.60	
	N	4	4	4

Desertification vs. Rainfall: A strong negative correlation ( $r = -0.78$ ) was found but was not statistically significant ( $p = 0.22 > 0.05$ ).

Desertification vs. Temperature: A weak negative correlation was found ( $r = -0.25$ ), also not statistically significant ( $p = 0.75 > 0.05$ ).

Interpretation of Statistical Relationships: The strong but statistically insignificant correlation with rainfall implies that while precipitation is a critical enabling factor, it is not the sole driver of the observed decadal-scale changes within this study's specific temporal sampling. The lack of significance is likely influenced by the small sample size ( $n=4$ ). Consequently, the Null Hypothesis ( $H_0$ ) that there is no significant correlation between desertification and climatic data in Yusufari cannot be rejected. This shifts the explanatory focus toward non-climatic, anthropogenic factors as the primary drivers of the observed greening.

### Integrated Synthesis and Implications

This integrated geospatial and statistical investigation presents a compelling case of land cover transition in a Sahelian environment. The key finding is a definitive regreening trend in Yusufari LGA, characterized by a 39.18% reduction in desert area (from 1,128.03 km<sup>2</sup> to 686.08 km<sup>2</sup>) and a 49.68% increase in vegetation cover (from 1,082.66 km<sup>2</sup> to 1,620.51 km<sup>2</sup>) between 1991 and 2021. This reversal occurred within a context of slightly more favourable rainfall but is not directly attributable to climate alone based on statistical evidence.

The landscape transformation follows a sequential recovery pathway: Desert Area → Bare Land (stabilized) → Vegetation. The persistence of extensive Bare Land (1,519.44 km<sup>2</sup>, representing 39.43% of the area in 2021) serves as a stark reminder of the landscape's latent vulnerability.

The study demonstrates the capacity of integrated GIS and remote sensing to provide empirical, spatially explicit data on environmental change. It reinforces that desertification is a dynamic process responsive to human action. The findings advocate for policies that recognize, support, and scale up the local practices and conditions that have driven this positive change, focusing on sustainable land management to consolidate the greening of Yusufari.

## SUMMARY OF FINDINGS

This study conducted a comprehensive geospatial and statistical analysis of desertification trends in Yusufari Local Government Area, Yobe State, Nigeria, over a thirty-year period (1991-2021), integrating time-series Landsat satellite imagery, climatic data, and GIS-based analytical techniques.

The central finding documents a pronounced regreening and desertification reversal trend in Yusufari. Contrary to expectations of advancing desert fronts, the analysis reveals a 39.18% contraction in desertified lands (sandy dunes and plains), declining from 1,128.03 km<sup>2</sup> in 1991 to 686.08 km<sup>2</sup> in 2021. This was complemented by a 49.68% expansion in vegetation cover, increasing from 1,082.66 km<sup>2</sup> (28.09%) to 1,620.51 km<sup>2</sup> (42.05%) of total land area. The transformation accelerated markedly after 2001, with the most rapid desert reduction occurring between 2001-2011 at an average rate of -21.12 km<sup>2</sup> per year.

Change detection analysis revealed complex recovery pathways. The primary greening mechanism was large-scale conversion of Bare Land to Vegetation at an average rate of 46.25 km<sup>2</sup>/yr during 2011-2021. Crucially, desert reduction was channeled through an intermediate transitional state of Bare Land, which gained from desert at rates of up to 21.12 km<sup>2</sup>/yr. This indicates a sequential recovery process: desertified sands stabilize into bare ground, which subsequently provides substrate for vegetation colonization. Bare Land thus emerges not merely as a degraded state but as a critical, dynamic intermediary in ecological restoration.

Climatic analysis showed marginal rainfall increase (from 409.1 mm in 1991 to 542.9 mm in 2020) and slight temperature rise (from 28.52°C to 28.47°C, with a peak of 29.56°C in 2010) over thirty years. While this may have enabled vegetation growth, statistical correlation revealed a critical insight: although a strong negative relationship existed between desertification extent and rainfall ( $r = -0.78$ ), this correlation was not statistically significant ( $p = 0.22 > 0.05$ ). Temperature correlation was weak and insignificant ( $r = -0.25$ ,  $p = 0.75 > 0.05$ ). The study therefore fails to reject the null hypothesis of no significant correlation between desertification and climatic variables in Yusufari. This outcome is pivotal: the dramatic desertification reversal cannot be attributed primarily to climatic variability. Instead, drivers must be sought in non-climatic, anthropogenic factors, pointing to significant agency of local communities in facilitating landscape restoration.

Bare Land remained the largest land cover class throughout the period, still covering 1,519.44 km<sup>2</sup> (39.43%) of Yusufari in 2021. This vast expanse represents a landscape in precarious equilibrium signifying both progress in reclaiming desert and latent threat of re-degradation. This land remains highly susceptible to rapid desertification if subjected to unsustainable pressure, prolonged drought, or abandonment of restorative practices.

## CONCLUSION AND RECOMMENDATIONS

### Conclusion

This research demonstrates that desertification in the Nigerian Sahel is not an inexorable, climate-driven fate but a reversible process influenced significantly by human action. The case of Yusufari LGA offers a compelling narrative of ecological hope and demonstrates the potential for dryland recovery. The findings underscore the critical importance of policies and interventions that support, reinforce, and scale up the local practices responsible for this positive change.

### Recommendations

- Based on the findings of this study, the following recommendations are proposed:
- Formal recognition and integration of successful indigenous land restoration knowledge into national action plans and policies.
- Targeted support for community-based natural resource management, including farmer-managed natural regeneration (FMNR), soil conservation techniques, and sustainable agroforestry practices.
- Continued monitoring using geospatial technologies to track progress, identify emerging threats, and adapt management strategies accordingly.
- Further research to precisely identify and quantify the specific socio-economic and agronomic practices driving the observed greening, including detailed field studies and participatory research with local communities.
- Investment in alternative energy sources to reduce pressure on woody vegetation for fuelwood and charcoal.
- Strengthening of institutional frameworks for land management at local, state, and national levels, with particular attention to securing land tenure for communities practicing sustainable land management.
- By adopting a nuanced understanding of land dynamics that values both ecological and human dimensions, sustainable development in the Sahel and similar dryland regions worldwide becomes a more attainable goal.

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